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Praca poglądowa/Review paper

Comparison of commercially available detectors used for the dosimetry of the High Energy Electron Beams

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Abstract

In modern radiotherapy, electron beams are used less and less often. However, there are still techniques where this type of particles is irreplaceable, like intraoperative radiotherapy (IORT) or total skin electron irradiation (TSEI). Due to low range of electrons penetrating the medium, dosimetric measurements and beam characteristics are challenging. One of the most important steps during this process is to select the right detector in order to collect reliable data. The purpose of this work was to perform beam characteristics using six commercially available detectors: Semiflex 3D (Type 31021), Advanced Markus (Type 34045), Markus (Type 23343), Roos (Type 34001), microDiamond (Type 60019), Diode E (Type 60017). Collected data shows various parameters describing electron beams, depending on the used detector. Obtained results showed that the most useful detector for beam characteristics is microDiamond Type 60019. Thanks to the very small effective volume, microDiamond showed a superior spatial resolution, which is especially handful during the measurements of dose profiles, allowing estimating beam parameters very precisely.

Introduction

The main purpose of radiotherapy is to deliver a precisely measured dose of ionizing radiation directly to the tumor volume, while reducing the dose distributed in the healthy tissue around the tumor and organs at risk. In the most cases, to achieve this goal, we use photon and electron radiation beams. However, electron beams are used relatively rarely in modern radiotherapy. Nevertheless, these particles still find use in some specific treatment techniques, such as integration of intraoperative radiotherapy (IORT), total skin electron irradiation (TSEI), treatment of skin cancer or combined with conventional photon radiotherapy as boost fields, especially during the breast radiotherapy. Electrons are also used in the newest, rapidly developing methods of treatment, like FLASH radiotherapy or focused VHEE (very high- energy electron) [1-3].

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A typical use of electron beams used for radiation therapy contains in the range from 4MeV to 22MeV. Electrons penetrating the medium have a finite range, highly dependent on their energy. The higher the energy of the electrons, the deeper they penetrate the matter, reaching the therapeutic depth at which the tumor is located. This property allows for using these particles to treat mainly shallow neoplastic lesions, placed close to the skin surface. [4]

Due to the low range of electrons in the medium, special care should be taken during the dosimetry measurements and quality assurance process, in order to collect accurate and reliable data. A small error in the position of the water phantom or setting the wrong reference position of the detector may result in a relatively large measurement error, which in turn induces a wrongly calculated dose distribution in the patient's body. [5]

There are several parameters describing electron beam quality. One of the most important is the beam quality index, calculated from R_{50} value. This parameter expresses the depth in the water, where the absorbed dose is equal to 50% of its value at the maximum. Measurement of the beam profiles allows to determinate several important parameters, like symmetry or flatness. Symmetry refers to the degree of similarity between the isodose curve on one side of the central axis versus the other. The beam flatness is assessed by finding the maximum D_{max} and minimum D_{min} dose point values on the beam profile within the central 80% of the beam width and then using the relationship. The next parameter is penumbra, defined as the area of sharp dose gradient (20%-80%). The value of penumbra is larger with decreasing the beam energy. At larger energies, the electron beam is less scattered in lateral direction, resulting in sharper penumbra region. [6-7]

Report TRS-398 published by the International Atomic Energy Agency (IAEA) contains all the necessary information and procedures describing dosimetric measurements of high energy electron beams. According to the TRS-398 report, the recommended ionizing chamber used for characteristics of the beam qualities should be a plane-parallel type, especially for the energies where $R_{50} < 4$ g cm^{-2}. Setting a proper reference point of the detector is a critical step. For plane-paraller chamber it should be on the inner surface of the entrance window, at the center and for cylindrical chamber it should be 0.5 r_{cyl} deeper than the surface of the water. [8]

Materials and Methods

All measurements have been performed on a medical linear accelerator produced by Varian Medical Systems. TrueBeam 2.7 (installed in Greater Poland Cancer Centre, Poznań, Poland) is able to generate several photon and electron beams. Available photon energies are 6MV, 15MV, 6FFF, 10FFF and 2.5MV (imaging beam) and electron beams: 6MeV, 9MeV, 12MeV, 15 MeV, 18MeV, 22MeV. Dose rate used in this study was 600 MU/min. [9]

To perform electron beam measurements in water, PTW Beamscan was used. Phantom itself provides many features, like auto-alignment and fully automated setup. Three-point measurement and advanced mathematical calculations allow for very precise positioning, aligning the scanning axes virtually to the surface water without moving the water tank.

Several different detectors (table 1) produced by PTW Freiburg have been used during this study for comparison of PDD and profiles in water: Semiflex 3D (Type 31021), Advanced Markus (Type 34045), Markus (Type 23343), Roos (Type 34001), microDiamond (Type 60019), Diode E (Type 60017). Each detector was precisely positioned in the central beam axis.

Table 1. Characteristic of ionizing detectors used in the study [10].

	Voltage	Chamber type	Volume	Total window area density
Semiflex 3D	400V	cylindrical	0.07cm³	84mg/cm²
Advanced Markus	300V	plane parallel	0.02cm³	106 mg/cm²

Markus	300V	plane parallel	0.055cm³	106 mg/cm²
Roos	200V	plane parallel	0.35cm³	132 mg/cm²
microdiamond	0V (polarity positive)	synthetic single crystal diamond detector	0.004mm³	101 mg/cm²
Diode E	0V (polarity negative)	silicon diode	0.03mm³	140 mg/cm²

After the measurement of percentage depth ionization using an ionizing chamber, it has to be converted to percentage depth dose. Depend of $R_{50,ion}$ displayed in centimeters, formula 1 or 2 should be used for calculations.

$$R_{50} = 1.029\ R_{50,ion} - 0.06 g/cm^2\ (I_{50} \leq 10cm) \quad (1)$$

$$R_{50} = 1.059\ R_{50,ion} - 0.37 g/cm^2\ (I_{50} > 10cm) \quad (2)$$

However, when using diode or diamonds detectors, conversion percentage depth ionization to percentage depth dose is not necessary. The mass collision stopping power ratios silicon to water are essentially constant with depth on a water phantom. After required conversions, D_{100}, D_{90}, D_{80}, D_{50} and the practical range are possible to compute. The beam quality might be also be describe using mean electron energy on the surface of the water phantom:

$$E_{p0} = 0.22 + 1.98 x R_p + 0.0025\ x\ R_p^2 \quad (3)$$

In regards to profiles measurements, several parameters describing the beam were obtained. Left and right penumbra (from 20% to 80% region) for each inplane and crossplane profile have been computed. Flatness and symmetry of the radiation beam for 20x20cm applicator size have been computed from 4 and 5 formulas.

$$\frac{(D_{max} - D_{min})}{(D_{max} + D_{min})}\ x\ 100\% \quad (4)$$

$$\frac{(D_{(x)})}{(D_{(-x)})_{max}}\ x\ 100\% \quad (5)$$

Results and discussion

The tables below contain detailed data of obtained percent depth dose measurements and beam profiles in the water phantom, for all six detectors used in this study. The first noticeable thing about PDDs is the significant difference between measurements performed with microDiamond, Diode E and the rest of the detectors. As mentioned before, measurements performed using the ionizing chambers should be first corrected, to take into account the water to air stopping power ratio. This effect is dependent on the initial energy of the electrons in the beam and the water depth. The difference of R_{50} range between microDiamond, Diode E and plane-parallel and cylindrical chambers is around 1.75% for lower energies and 0.50% for higher energies. According to the international reports and guidelines, cylindrical chambers are not recommended for measuring electron PDDs, but they can be used for acquiring beam profiles. Difference in R_{50} range for lower energies between cylindrical chamber and microDiamond/Diode E is almost 4.00%. We observed the biggest deviations in the region of steep dose gradients, because of different spatial averaging of each detector. To avoid spikes during data acquisition, we set a small measurement step (0.50mm) and the lowest possible speed of movement of the detector in the water phantom.

Table 2. Parameters of PDD for six different energies used in the study.

Ionizing Chamber	Energy [MeV]	R100 [mm]	R90 [mm]	R80 [mm]	R50 [mm]	RP [mm]	Ds. [%]	Ep0 [MeV]
Roos	6	12.90	17.59	19.51	23.44	29.40	80.05	6.06
	9	20.20	27.53	30.17	35.67	43.44	83.41	8.87
	12	28.20	38.90	42.55	49.90	60.05	87.91	12.20
	15	31.30	48.52	53.45	62.87	75.54	92.13	15.32
	18	23.90	55.81	62.90	75.32	90.83	94.70	18.41
	22	20.10	60.21	70.69	87.42	106.57	94.72	21.60
Advanced Markus	6	13.00	17.63	19.52	23.49	29.47	79.61	6.08
	9	20.40	27.53	30.20	35.66	43.55	83.29	8.89
	12	28.80	38.86	42.49	49.81	60.01	87.77	12.19
	15	31.30	48.48	53.38	62.79	75.54	91.89	15.32
	18	22.80	55.85	62.87	75.31	90.87	94.30	18.42
	22	21.70	60.21	70.75	87.47	106.55	94.31	21.60
Markus	6	12.80	17.39	19.23	23.25	29.27	79.68	6.04
	9	20.70	27.33	30.00	35.45	43.57	82.91	8.89
	12	28.20	38.67	42.34	49.55	59.99	87.45	12.19
	15	32.10	48.46	53.27	62.55	75.39	91.77	15.29
	18	26.20	55.86	62.94	75.11	90.82	94.44	18.41
	22	20.80	60.68	70.85	87.20	106.31	94.53	21.55
microDiamond	6	13.99	18.15	20.05	23.87	29.64	76.39	6.11
	9	21.99	28.24	30.75	36.06	43.86	80.42	8.95
	12	30.02	39.74	43.23	50.37	60.43	85.11	12.28
	15	33.00	49.41	54.27	63.43	75.79	89.58	15.37
	18	27.00	56.81	63.96	75.96	91.08	92.17	18.46
	22	20.02	60.38	71.32	87.92	107.15	91.68	21.72
Diode E	6	13.99	18.34	20.17	24.03	29.68	76.37	6.12
	9	21.98	28.46	31.01	36.31	43.92	80.94	8.96
	12	29.96	39.77	43.42	50.53	60.44	85.86	12.28
	15	32.02	39.42	54.22	63.49	75.82	90.03	15.38
	18	24.02	56.61	63.63	75.96	91.26	92.60	18.50
	22	22.99	60.51	71.27	88.13	107.09	92.56	21.71
Samiflex 3D	6	12.20	17.05	19.02	23.12	29.32	77.22	6.05
	9	20.10	27.09	29.82	35.38	43.35	80.13	8.85
	12	28.20	38.64	42.30	49.60	59.91	84.72	12.17
	15	33.00	48.58	53.39	62.68	75.30	89.23	15.27
	18	29.20	56.71	63.38	75.39	90.59	92.42	18.36
	22	23.90	61.98	71.73	87.72	106.26	92.83	21.54

Graph bellow present percent depth doses curves obtained with microDiamond for 6MeV, 9MeV, 12MeV, 15 MeV, 18MeV, 22MeV. During data acquisition the lowest scanning speed was use, so additional smoothing in the software was not required.

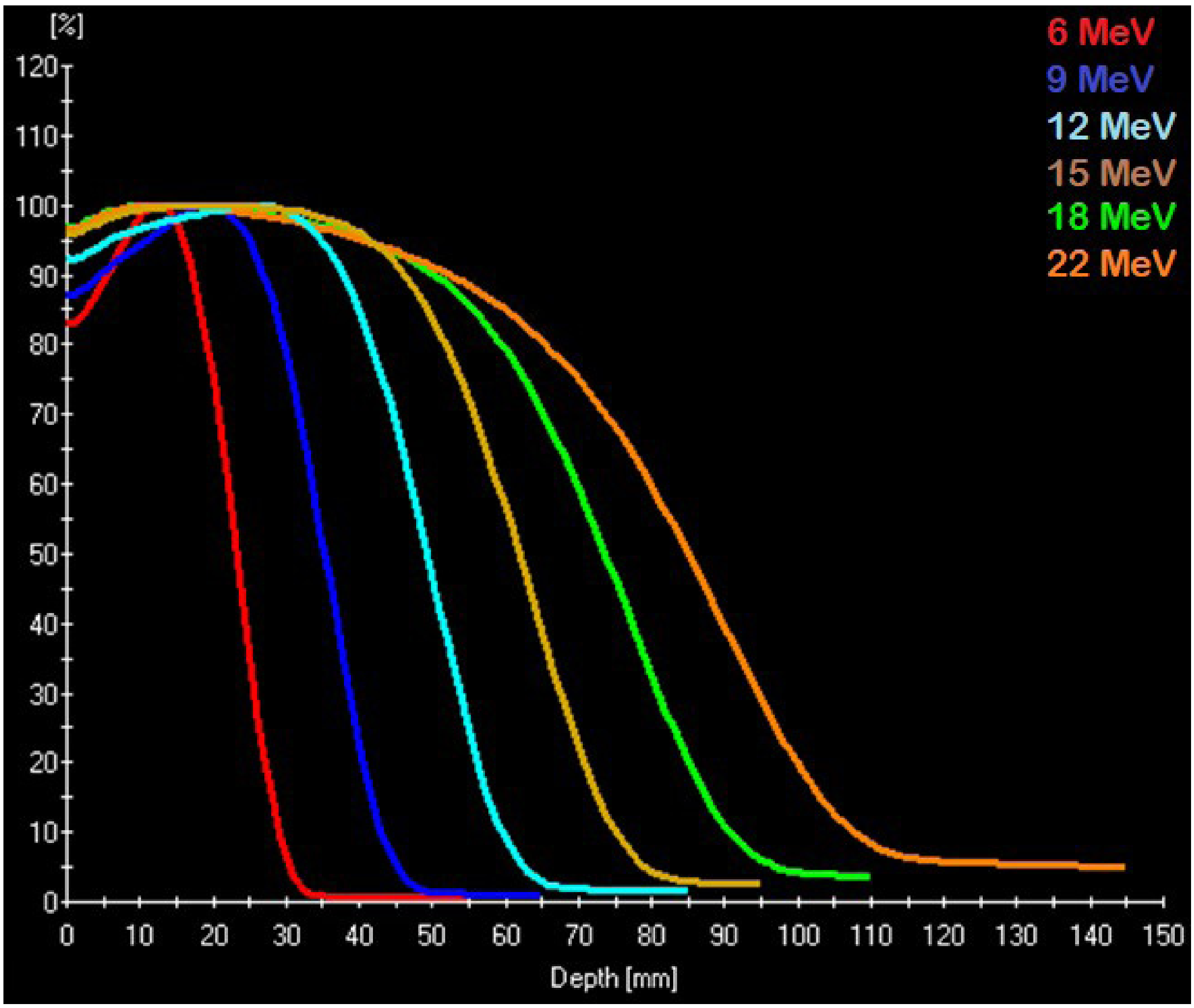

Figure 1. PDDs measurement performed with microDiamond (type 60019) for six different electron beams.

In regards to the dose profile measurements, they were performed for a 20x20cm applicator. Table 3 consists data collected for in-plane profiles and table 4 consists data for cross-plane profiles. Penumbra is defined in the range from 20% to 80% of the beam intensity. For 6 MeV electron beams every plane-parallel chamber shows a tendency to have a slightly larger penumbra. Its value is also increasing if the effective volume of the detector is larger, due to spatial averaging. This effect is most pronounced for the Roos ionizing chamber, which had the largest effective volume across all detectors used in this study. Furthermore, microDiamond and Diode with the very small effective values, we obtained the smallest penumbra values. Slightly lower values were obtained by diamond.

Table 3. Collected data for in-plane beam profiles.

Ionizing Chamber	Energy [MeV]	Pen. Left [mm]	Pen. Right [mm]	Flatness [%]	Symmetry [%]
Roos	6	14.85	14.73	2.36	100.85
	9	14.41	14.40	1.27	100.44
	12	15.27	15.23	1.11	100.51
	15	16.44	16.27	1.40	100.71
	18	17.62	17.21	1.93	101.39
	22	21.09	20.65	2.85	101.32
Advanced Markus	6	12.12	12.11	2.02	100.83
	9	11.98	11.97	1.15	100.45
	12	13.06	13.05	1.27	100.53
	15	14.44	14.34	1.08	100.66
	18	15.72	15.33	1.58	101.34
	22	16.84	16.53	1.84	101.15
Markus	6	12.25	12.19	2.07	100.85
	9	12.12	12.08	1.20	100.36
	12	13.19	13.07	1.30	100.59
	15	14.54	14.30	1.19	100.89
	18	15.87	15.30	1.67	101.56
	22	16.91	16.38	2.05	101.53
Diode E	6	10.53	10.70	2.07	100.93
	9	10.86	10.86	1.38	100.93
	12	12.08	12.10	1.31	100.79
	15	13.63	13.49	1.30	100.67
	18	15.06	14.46	1.54	101.46
	22	16.20	15.82	2.07	101.33
microDiamond	6	10.39	10.43	1.98	100.87
	9	10.49	10.54	1.20	100.57
	12	11.76	11.79	1.31	100.44
	15	13.30	13.16	1.12	100.48
	18	14.75	14.27	1.35	101.40
	22	16.04	15.65	2.01	101.14
Semiflex 3D	6	11.85	11.91	1.98	100.86
	9	11.87	11.95	1.13	100.37
	12	13.09	13.13	1.17	100.50
	15	14.47	14.37	1.16	100.72
	18	15.75	15.38	1.61	101.35
	22	16.86	16.49	2.01	101.34

Table 4. Collected data for cross-plane beam profiles.

Ionizing Chamber	Energy [MeV]	Pen. Left [mm]	Pen. Right [mm]	Flatness [%]	Symmetry [%]
Roos	6	14,62	14,96	2,48	101,27
	9	14,28	14,36	1,19	100,62
	12	15,16	15,18	0,93	100,29
	15	16,31	16,19	1,07	100,38
	18	17,30	17,23	1,13	100,14
	22	20,69	20,65	2,10	100,19
Advanced Markus	6	11,81	12,12	2,02	100,58
	9	11,63	11,72	1,32	100,62
	12	12,75	12,91	1,18	100,77
	15	14,15	14,12	1,17	101,21
	18	15,33	15,27	1,10	100,81
	22	16,52	16,27	1,79	101,16
Markus	6	11,82	12,11	1,95	100,65
	9	11,77	11,88	1,37	100,66
	12	12,90	13,05	1,27	100,72
	15	14,18	14,16	1,23	101,10
	18	15,27	15,25	1,21	100,87
	22	16,39	16,24	1,76	101,24
Diode E	6	10,56	10,66	2,34	101,24
	9	10,66	10,67	1,29	100,68
	12	11,94	11,89	1,34	100,92
	15	13,34	13,17	1,35	101,13
	18	14,68	14,53	1,08	101,09
	22	15,78	15,61	1,62	100,94
microDiamond	6	10,14	10,38	2,13	101,21
	9	10,33	10,39	1,18	100,44
	12	11,57	11,64	1,10	100,42
	15	12,98	12,95	1,14	100,72
	18	14,30	14,23	0,83	100,64
	22	15,62	15,43	1,72	100,83
Semiflex 3D	6	11,46	11,65	1,83	100,54
	9	11,59	11,70	1,25	100,73
	12	12,85	12,94	1,19	100,62
	15	14,17	14,08	1,12	100,92
	18	15,31	15,27	1,04	100,64
	22	16,51	16,30	1,62	100,84

Conclusion

Performing reliable and accurate dosimetric measurements in order to characterize the radiation beam is a critical step for collecting relevant results. Data collected during the commissioning process has a very strong impact on the final dose calculation in the treatment planning system. In this study, we used six different, commercially available detectors to measure PDDs and dose profiles of high-energy electron beams. Obtained results showed that the most useful detector for electron beam characteristic is microDiamond Type 60019. Thanks to the very small effective volume, microDiamond showed a superior spatial resolution, which is especially handful during the measurements of dose profiles, allowing estimating the beam penumbra very precisely. Moreover, during PDD curves, conversion percentage depth ionization to percentage depth dose was not necessary.

References

[1] L. Whitmore, R. I. Mackay, M. van Herk, J. K. Jones & R. M. Jones. Focused VHEE (very high energy electron) beams and dose delivery for radiotherapy applications. *Scientific Reports volume 11, Article number: 14013 (2021).*

[2] Jonathan R Hughes 1, Jason L Parsons. FLASH Radiotherapy: Current Knowledge and Future Insights Using Proton-Beam Therapy. *International Journal of Molecular Sciences, 21 (2018).*

[3] Xiaohui Wang,Hui Luo,Xiaoli Zheng,Hong Ge. FLASH radiotherapy: Research process from basic experimentation to clinical application. *Precision Radiation Oncology 5 (2021).*

[4] Kukołowicz P. F. Charakterystyka wiązek terapeutycznych fotonów i elektronów *(2017).*

[5] Julian Malicki, Krzysztof Ślosarek. Planowanie leczenia i dozymetria w radioterapii *(2018).*

[6] C.Di Venanzio, Marco Marinelli, A.Tonnetti, G.Verona-Rinati, M.D. Falco, M.Pimpinella, A.Ciccotelli, S.De Stefanod, .Felici, F.Marangoni. Characterization of a microDiamond detector in high-dose-per-pulse electron beams for intra operative radiation therapy. *Physica Medica 1-6 (2015).*

[7] Chang Yeol Lee, Woo Chul Kim, Hun Jeong Kim, Hyun Do Huh, Seungwoo Park, Sang Hyoun Choi, Kum Bae Kim, Chul Kee Min, Seong Hoon Kim & Dong Oh Shin. Comparative dosimetric characterization for different types of detectors in high-energy electron beams. *Journal of the Korean Physical Society volume 70 (2017).*

[8] IAEA TRS 398. Absorbed Dose Determination in External Beam Radiotherapy. An International Code of Practice for Dosimetry Based on Standards of Absorbed Dose to Water. Tehnical Report no 398 *(2006).*

[9] Varian Medical Systems, TrueBeam specifications, Varian Medical Systems International AG Cham, *(2013)*

[10] PTW-Freiburg, Detectors for Ionizing Radiation, Codes of Practice *(2022).*